(NASA-CR-186444) MAGELLAN: MISSION TO VENUS (Martin Marietta Corp.) 21 p

N90-71303

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Magellan
Mission to Venus

INTRODUCTION

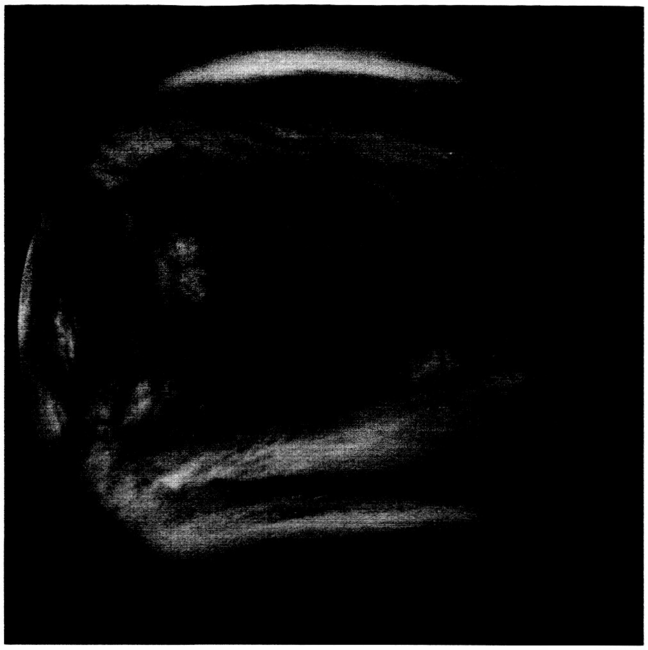

Figure 1 Venus

The National Aeronautics and Space Administration (NASA) mission to map the hidden surface of Venus with the Magellan spacecraft is the capstone of a grand experiment to study the inner solar system. This research, spanning 25 years, has sent spacecraft to study Mars, the Moon, Mercury and Venus—worlds which share a similar origin. Of these, Venus is most like Earth in size, age, composition, and distance from the Sun. It also exhibits some striking differences. Most importantly, it is the inner planet of which we have the least information.

On Venus lie many of the missing chapters in our understanding of the solar system's and Earth's evolution. The geologically stable worlds of Mars, Mercury and the Moon show what the interior planets looked like shortly after they were born. They represent the first 5% of solar system history.

At the other end is the geologically dynamic Earth which has continued to evolve and is changing to this day. Its surface has been completely recycled by plate tectonics 20 times. Only the most recent 5% of its geologic record remains for us to study.

It is like trying to understand an entire book from only the first and last chapters.

To read the missing chapters on Venus, we must have a clear and detailed picture of the entire surface. That surface has been hidden by a very dense atmosphere with opaque clouds. Using Magellan's radar imaging, we will be able to see detail that matches or exceeds what we have from any other planet.

So why is it important that we learn about this missing geological history? As we look at the planets of the solar system, we notice that the physical characteristics and proximity to the Sun of Venus, Earth and Mars suggest they should be far more alike. All began about the same time under similar conditions and made of the same materials.

The three planets, however, followed very different evolutionary paths. Mars lost most of its water and atmosphere to become a frigid desert. On Venus, the atmosphere compressed and clouded over to cook the planet in an out-of-control "greenhouse effect." Only Earth evolved to support an incredibly rich variety of life.

Why did these planets go different ways? That is a fundamental question the 25-year exploration of the solar system seeks to answer. It is critical to our understanding of Earth's past and, quite possibly, its future. The Magellan mission is expected to provide us an incredible wealth of clues to the answer.

VENUS

In the fading light of sunset and dawn, Venus often can be seen sparkling near the horizon as the brightest celestial body traversing our night sky, excepting the Moon. Alternatively called the Evening Star or the Morning Star, it has been a familiar object to poets, astronomers and navigators for aeons. It was undoubtedly recognized by the explorer Magellan on his journey as one of the few familiar stars in the skies of the southern hemisphere. But for all its familiarity, Venus has stubbornly remained an enigma.

Of all the planets in the solar system, Venus is Earth's nearest neighbor with an orbit 25.7 million miles away. It is often referred to as Earth's twin or sister because of the two planets' similarities. They are nearly the same in size, mass, density, composition, age, relative proximity to the Sun, and possession of an atmosphere with clouds.

Such similarities once spawned imaginative concepts of a steamy, verdant world. We now know the measured similarities probably go no further.

Planetary Comparisons

	Venus	Earth
Mean Distance from Sun	67.2 Million Miles	93 Million Miles
Sidereal Period of Revolution	224.7 Earth Days	365.26 Days
Length of Day	243 Earth Days	24.6 Hours
Diameter	7519 Miles	7926 Miles
Density	3.0 oz/cu in.	3.2 oz/cu in.
Mass	0.815 x Earth	1
Geologic Composition	Metal & Silicate Rock	Metal & Silicate Rock
Solar Radiant Energy	2.3 x Earth's	1
Surface Temperature	900°	80°
Atmosphere	Carbon Dioxide	Nitrogen, Oxygen
Atmospheric Pressure	92 Bars	1 Bar

Previous planetary missions have revealed a surface temperature of 900°F, a carbon dioxide atmosphere with sulfuric acid rain, and an atmospheric pressure equal to that 2500 ft. deep in a terrestrial ocean. Venus has no water or water vapor, no moon, and no magnetosphere. The planet's retrograde rotation makes the Sun rise in the west and set in the east. It turns so slowly that a Venusian day is longer than a Venusian year, with the demarcation between day and night moving at the speed of a steady walk.

The perpetual cloud cover of carbon dioxide traps heat in a "greenhouse effect" gone berserk. It also has been an effective barrier to telescopic study that has only been able to observe the 225-mile-an-hour circulation of upper atmospheric clouds.

During the space age, there have been 20 trips to Venus by the U.S. and Soviet Union carrying low-resolution radar and other sensors. A few photographs taken during the brief lives of Soviet landers on the surface have shown tantalizing details of a tiny fragment of landscape.

Radar from Earth and planetary probes has shown raised land masses and the suggestion of peaks, volcanos, craters and canyons. More specific knowledge of our neighbor remains veiled behind the drawn curtain of clouds.

Venus Probes

1961	Venera 1	USSR	1972	Venera 8	USSR
1962	Mariner 2	US	1974	Mariner 10	US
1964	Zond 1	USSR	1975	Venera 9 & 10	USSR
1966	Venera 2 & 3	USSR	1978	Pioneer Venus 1 & 2	US
1967	Venera 4	USSR		Venera 11 & 12	USSR
	Mariner 5	US	1982	Venera 13 & 14	USSR
1969	Venera 5 & 6	USSR	1983	Venera 15 & 16	USSR
1970	Venera 7	USSR	1985	Vega 1 & 2	USSR

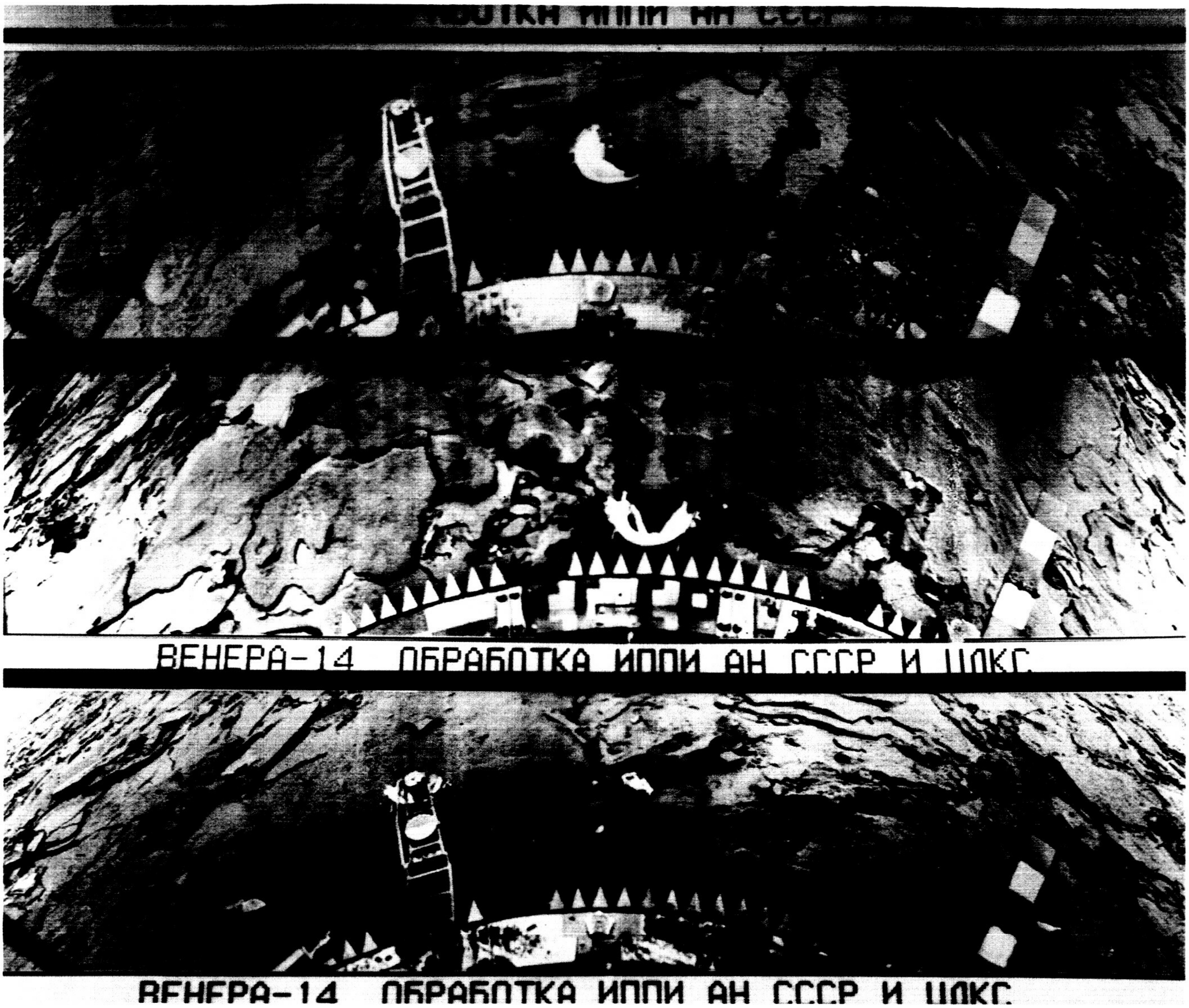

Figure 2 Surface of Venus Photographed by Soviet Venera 13 and 14 Landers

SPACECRAFT

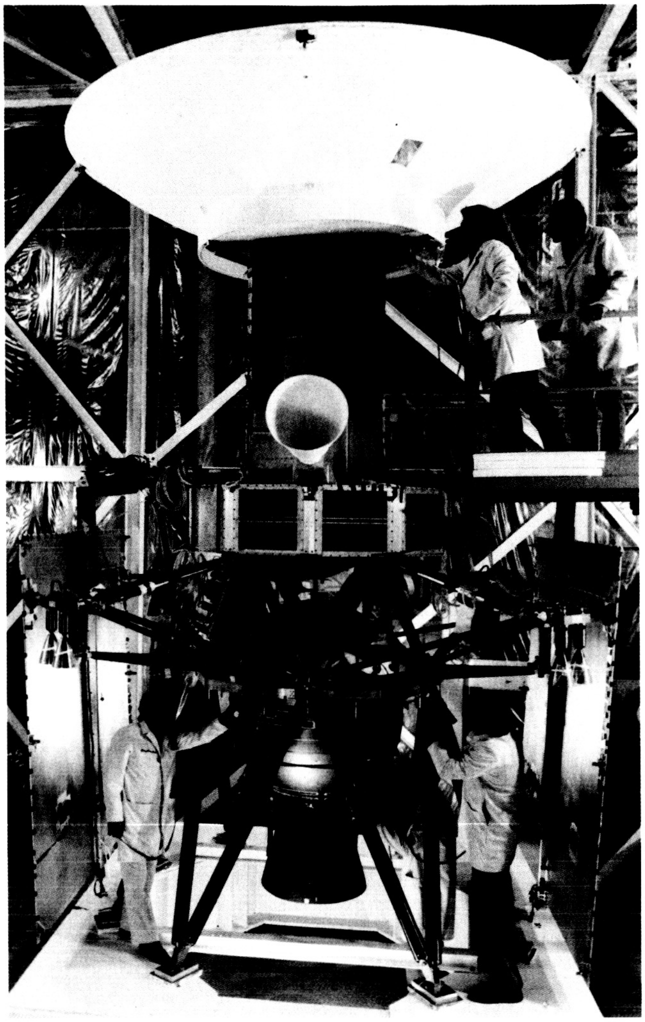

Figure 3 Magellan Spacecraft during Tests at Martin Marietta

The wealth of knowledge we expect to acquire about Venus, the inner solar system and Earth will be due, in large part, to a single, extraordinary spacecraft named Magellan carrying only one science instrument—radar. Yet it will transmit to Earth more data than all previous planetary missions combined.

In addition to its special contribution to science, Magellan has a distinctive place in the current U.S. space program. It is the first planetary mission to be launched by the space shuttle. It is the first to use a complex, Sun-circling "Type 4" trajectory to reach a planet. And it is the first of a series of missions resuming deep space research since the launch of the Pioneer Venus probes 11 years ago.

Magellan is named after the Portuguese explorer Ferdinand Magellan whose expedition circumnavigated the world in the 1520s—a time when people still believed the Sun, planets and stars revolved around an Earth comprised mostly of land marked on maps as "Terra Incognita." His journey revealed the vaster nature of Earth and the distribution of broad oceans and continents. Similarly, the spacecraft Magellan is expected to provide a global understanding of the poorly known surface of Venus.

NASA began concept studies of a radar imaging probe to explore the Venusian surface, called the Venus Orbital Imaging Radar (VOIR), in 1971 at Jet Propulsion Laboratory and Martin Marietta. The project was cancelled in 1982 for budget reasons, then reinstated in the 1984 NASA budget as the Venus Radar Mapper on the understanding that the spacecraft be built for about half the originally estimated cost.

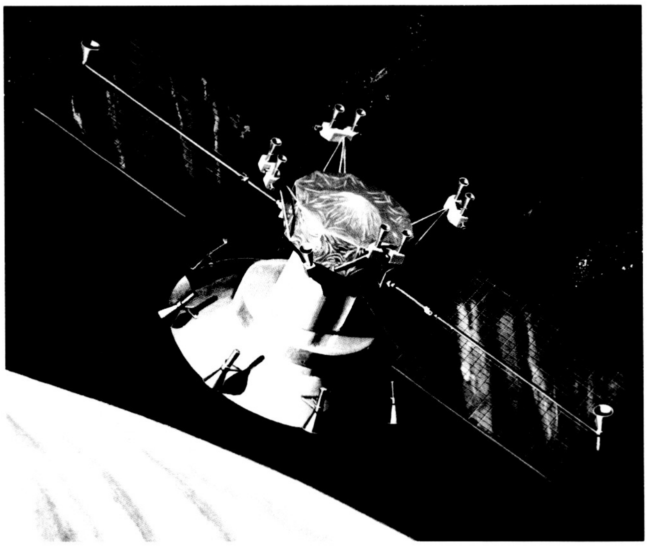

Figure 4 Venus Orbital Imaging Radar (VOIR) Spacecraft

By then, the U.S. had accumulated an inventory of mission-proven technologies and spare components from the Viking, Voyager, Galileo and other planetary research projects. These were scoured for whatever they could provide the Venus project to save the costs of designing equipment from scratch. The adjacent table shows Magellan subsystems that are either spares or existing designs updated and modified for Magellan.

Also, advances in data processing and other software enabled a simpler design to perform more complex tasks. For example, instead of separate antennas for mapping and telemetry, the craft was redesigned to make the high-gain

Subsystems from Other Spacecraft

Component	Source
Medium Gain Antenna	Mariner 9 Mars
High Gain Antenna	Voyager
Equipment Bus	Voyager
Star Scanner Design	IUS
RF Traveling Wave Tube Assemblies	Ulysses
Attitude Control Computer	Galileo
Command and Data System	Galileo
Thruster Rockets	Voyager
Electric Power Converter	Galileo
Power Control Unit	P-80
Gyroscope Design	Viking
Pyrotechnic Control	Galileo
Solid Rocket Motor Design	PAM
Propellant Tank Design	Space Shuttle APU

antenna do double duty. With only the loss of a few experiments and small compromises in telecommunications, Magellan was on track again.

Then the Challenger disaster in 1986 threw another hitch in the journey to Venus. The explosion led to the re-evaluation and cancellation of the Centaur G-Prime booster for use on the shuttle. The most powerful upper stage ever designed, Centaur was to have shot Magellan to Venus on a 4-month trajectory. Its explosive liquid oxygen and hydrogen propellants, however, were deemed too dangerous to be carried in a manned space vehicle.

The less powerful Inertial Upper Stage (IUS) replaced Centaur as the booster for Magellan, requiring some modifications to designs and plans. The aluminum Centaur adapter structure was replaced with a lighter, graphite-epoxy frame. A lighter spring mechanism could also be used to separate the less massive IUS after burnout.

The launch procedure was changed to deploy the solar arrays before ignition of the IUS because the booster's roll control thrusters were too close to the ends of the solar panels in their stowed position. Lastly, rather than subject the entire spacecraft to a repetition of full-up static tests in the new IUS configuration, a mockup Magellan was constructed for the tests. Fidelity was assured by using a real Voyager bus borrowed from a public display at the Smithsonian Institution.

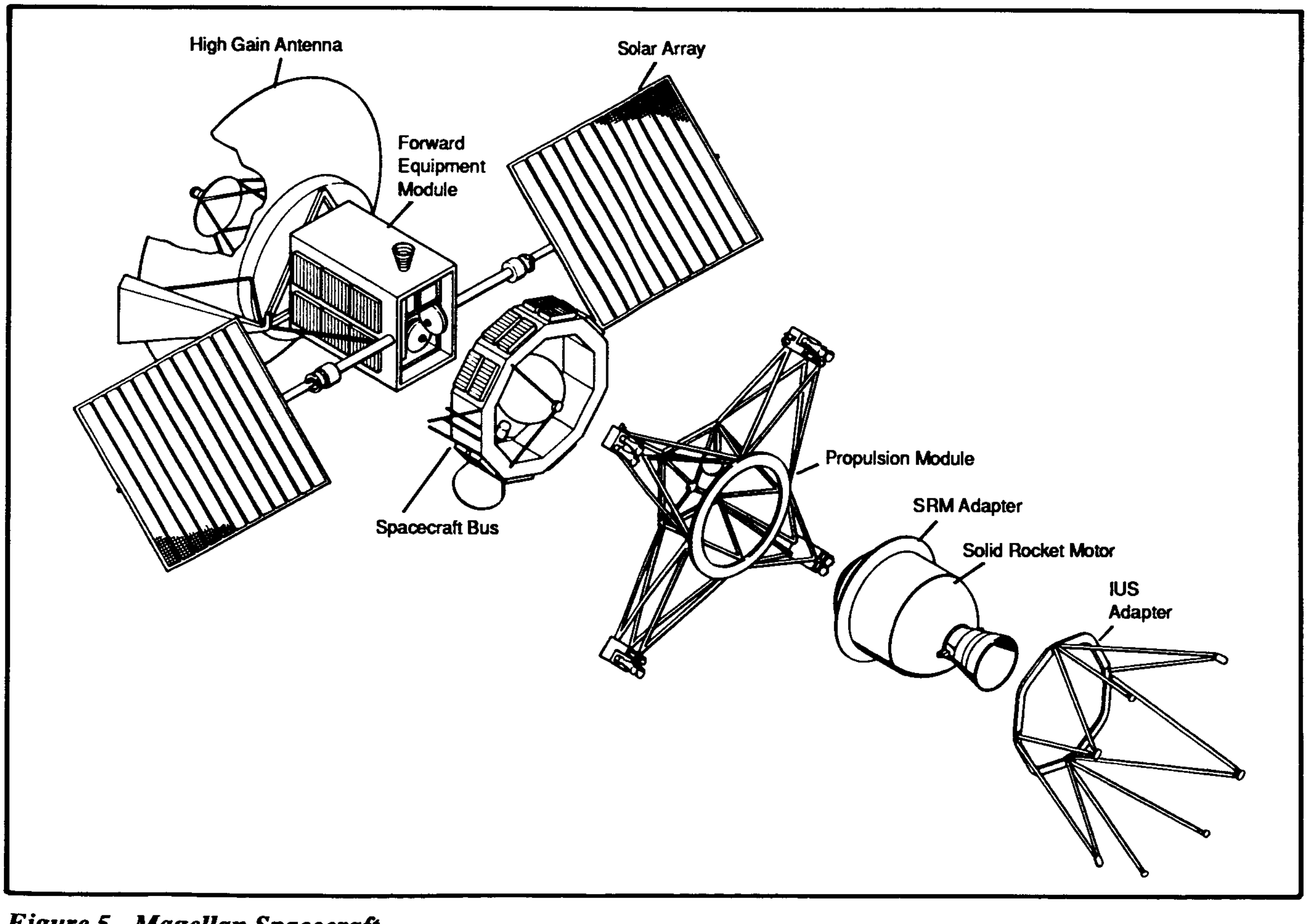

Figure 5 Magellan Spacecraft

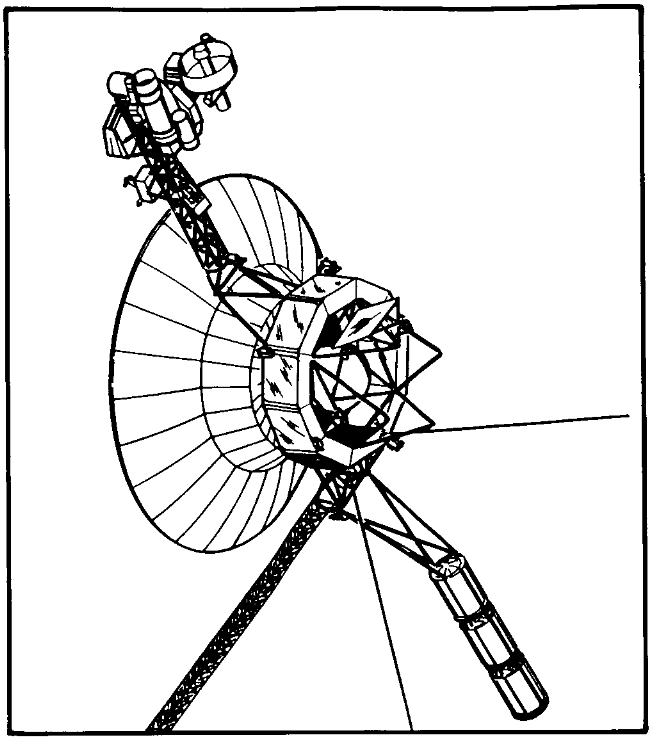

Figure 6 Voyager Spacecraft

The loss of the Challenger vehicle and the 32-month suspension of shuttle missions delayed and reshuffled many planned space activities. The Galileo mission to Jupiter, for one, would have to launch on the date originally set aside for Magellan or wait another two years for the necessary alignment of planets to repeat. The result was a late April launch for Magellan and the first use of a complex, Sun-circling "Type 4" trajectory.

Thus, the $530 million mission and spacecraft that will launch in April are much different than NASA had planned a decade before, yet the scientific objectives that will be achieved remain almost unchanged.

OVERALL STRUCTURE

The Magellan mission vehicle as it is loaded in the space shuttle cargo bay is a stack consisting of:

1) Antennas—high-, medium- and low-gain, plus altimetry,
2) Forward equipment module,
3) Equipment bus,
4) Solar panels,
5) Propulsion module,
6) Solid rocket orbit insertion motor,
7) Adapter structure,
8) Inertial Upper Stage.

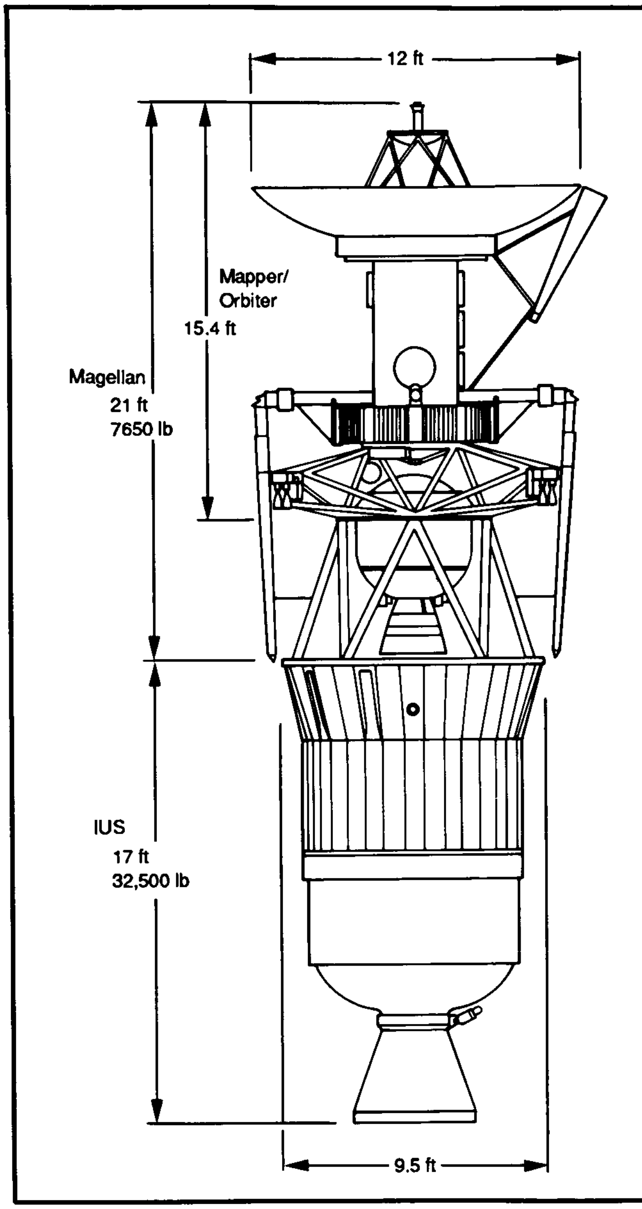

Figure 7 Magellan and IUS As Carried in Shuttle Cargo Bay

ANTENNAS

The large, parabolic, high-gain antenna is instrumental to all aspects of the mission:

1) transmission and reception of the mapping radar pulses;
2) transmission of science data to Earth;
3) detection of radiant energy emitted by Venus; and
4) reception from Earth of commands directing normal spacecraft activities.

The dish is made of extremely strong, lightweight graphite epoxy sheets mounted to an aluminum honeycomb for rigidity.

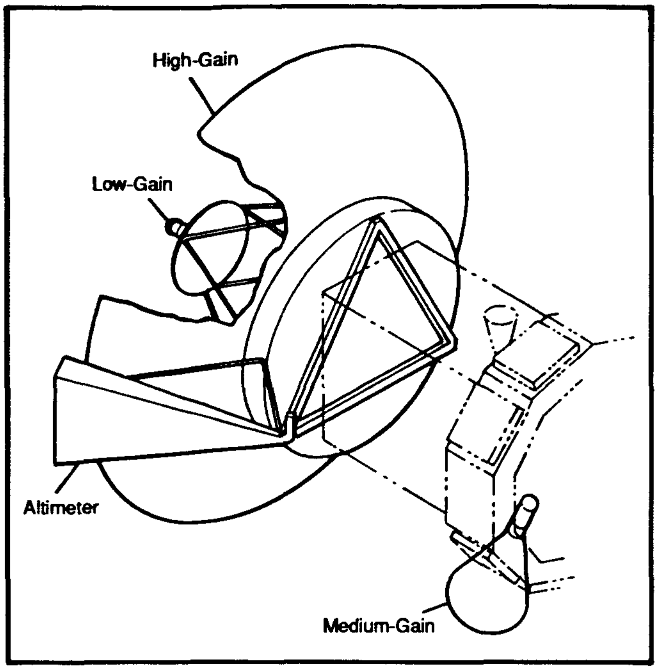

Figure 8 Antennas

Suspended on graphite-epoxy struts above the center is the low-gain antenna. It provides ground teams with an alternative means of commanding the spacecraft in case of an emergency that prevents use of normal frequencies. An example would be an unexpected solar flare that interferes with the mission and command transmissions. Using the low-gain frequency, mission control can command Magellan to suspend mapping and go into a "safe attitude," solar panels facing sunward, until normal communications links resume.

Mounted to one side of the high-gain dish is the altimeter antenna. During the mapping part of each Venus orbit, this radar antenna is pointed vertically down at the surface to provide one-dimensional readings of the heights of geologic features (the high-gain antenna is aimed obliquely to the spacecraft's direction of travel). The 5-foot-long graphite-epoxy structure has an aperture 2 by 1 feet and weighs 14 pounds.

At the bottom and one side of the forward equipment module is the conical medium-gain antenna. It is used for commands to and engineering data from Magellan during the 15-month cruise from Earth.

FORWARD EQUIPMENT MODULE

The forward equipment module houses the synthetic aperture radar electronics, telecommunications, spacecraft navigation, batteries and power distribution controls. The box-like housing, 5.3 by 3 by 4 feet, is made of aluminum panels on a framework of square aluminum tubing that has been chemically milled for weight reduction. Two sides of the box have louvers for thermal conditioning. Solar reflector coverings shield the louvers from the intense sunlight at Venus.

Synthetic Aperture Radar (SAR) Sensor

This method of "seeing" is the heart of the Magellan mission. The visually opaque clouds of Venus are transparent to the 2.385-gigahertz radio frequency SAR transmits and receives through the parabolic antenna.

In the same way a flashlight pierces the darkness of a room and reflects off objects to reveal their position, shape and texture, Magellan's antennas are flashlights in an invisible part of the electromagnetic spectrum. The antennas also serve as "eyes" that enable the SAR sensor to receive the reflected electromagnetic waves.

The altimetry radar receives a narrow angle of reflected signals to measure an object's altitude in the same way military radar indicates a target's distance and speed. Precise altitude is determined by the time lapse between a radar transmission pulse and the echo's return. Since a radar pulse travels at light speed, the difference is a fraction of a second. Magellan's radar electronics adjust the timing of radar pulses for spacecraft altitude, which is continually changing, to give measurements accurate within 150 feet.

The radar used for images receives a much broader beam of reflected signals. Like the flashlight in the dark, radar pointed obliquely to a surface will show more shape and texture than a head-on aim. As Magellan maps, the large antenna will be aimed to the side of the spacecraft's track over the planet, striking the surface at an angle. The angle ranges between 19° and 52° with Magellan's altitude.

Imaging radar acquires two-dimensional image data. One dimension is provided by the time for radar echoes to return, the other dimension is provided by Doppler effect. Doppler effect causes frequency and wavelength to shorten as a surface feature is approaching, and lengthen as it recedes.

Synthetic aperture refers to the size of the antenna for receiving the echoes. The larger the antenna (its aperture), the better the image quality will be. Because the antenna moves a distance during the time it receives an echo, it simulates the reception of a much larger dish. The distance Magellan travels while a surface feature is within the SAR's field of view for receiving determines the functional size of the antenna.

This synthetic aperture dimension varies as the spacecraft's velocity varies along the eliptical orbit. The greatest speed

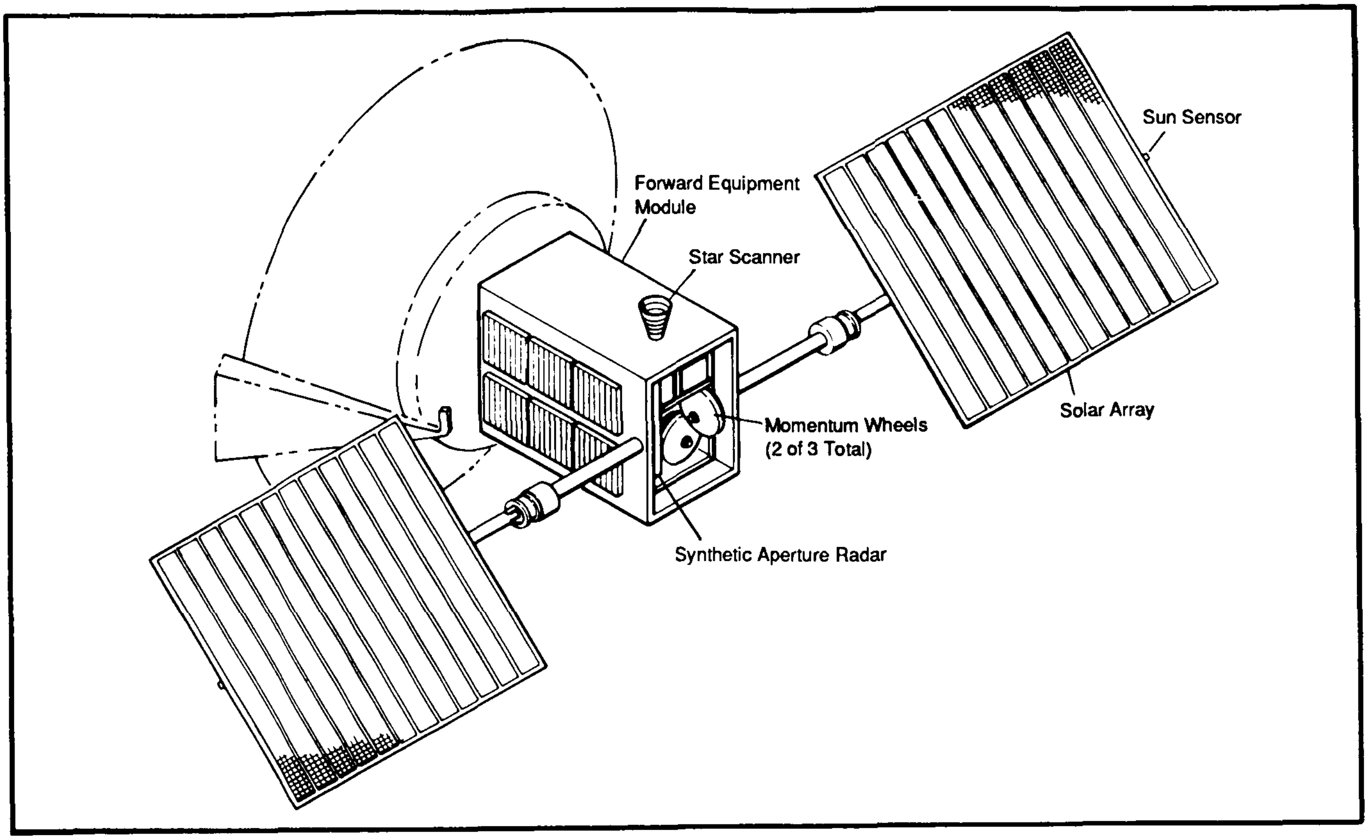

Figure 9 Forward Equipment Module and Solar Arrays

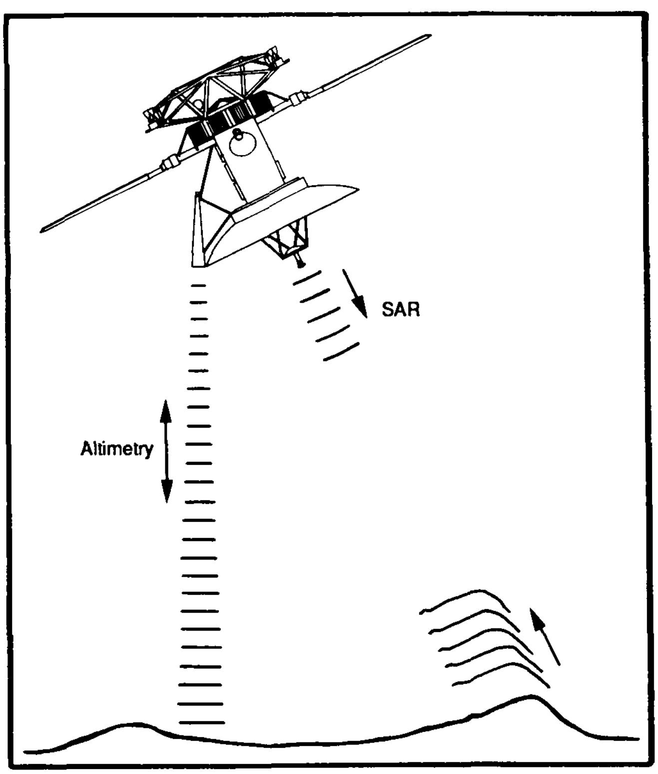

Figure 10 Altimetry and Imaging Radars

and, hence, greatest aperture and imaging accuracy are at the periapsis north of the equator where images will have a resolution close to 300 feet.

The SAR electronics must also compensate for Magellan's changing speed and altitude from Venus and for large variations in the planet surface with adjustments in transmission wavelength and frequency.

In addition to radar altimetry and imaging, the sensor system detects radiant energy emitted by Venus and received by the high-gain antenna.

The electronics which perform SAR, altimetry and radiometry occupy nearly 20% of the forward equipment module's volume. Developed by Hughes Aircraft Company, the system controls the frequencies of the radar pulses, adjusts them for movement of the spacecraft, and interprets the returning reflections as points of brightness values that will constitute a photo-like image.

The sensor system is in 37 modules racked in a 5- by 3- by 1-foot enclosure and weighing 340 pounds. It includes 177 two-sided circuit boards and 28 multi-layered circuit boards with 15,000 electronic parts and 22,000 other parts such as resistors and capacitors. The wiring harness has some 4500 terminations.

All of the components comprising the system are in redundant pairs for insurance. During mapping, the system uses 200 watts of electricity—the equivalent of a bright floor lamp. The data are stored in tape recorders located in the spacecraft bus until transmission.

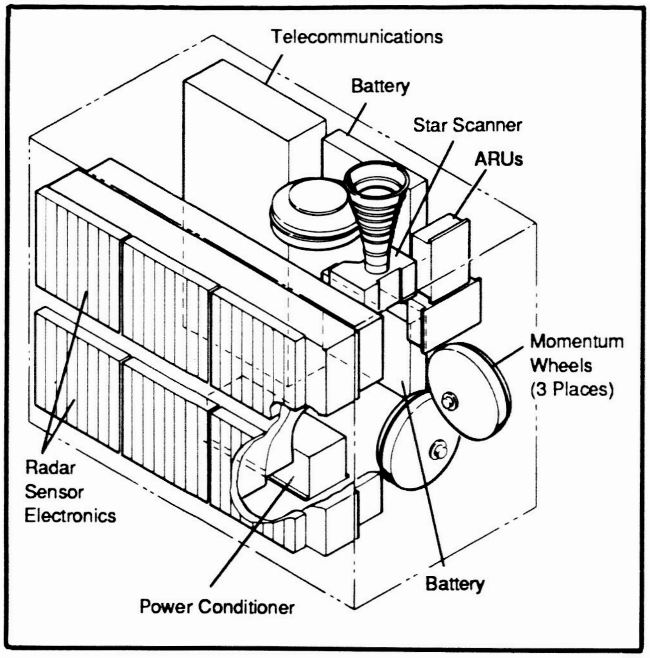

Figure 11 Forward Equipment Module Electronics

Telecommunications

The ability to acquire detailed knowledge of Venus' surface depends as much on Magellan's ability to send large amounts of data to Earth as on the radar equipment. Most of the communications equipment for receiving, sending and decoding radio signals is located in the forward end of the equipment module. Its NASA-standard transponder and traveling wave tube assemblies enable Magellan to transmit at a peak rate of 268.8 kilobits per second. In comparison, the Viking orbiter in 1976 could transmit its detailed images of Mars at 2 kilobits per second.

From Venus orbit, the system will send to Earth engineering data on the spacecraft's condition at 115.2 kilobits per second through the medium-gain antenna, or at 1.2 kilobits per second through the high-gain antenna simultaneous with the science data. Engineering data can be transmitted in real time or from memory. Other telemetry downlink and command uplink capabilities use different data rates and the medium-gain antenna. The low-gain antenna is reserved for receiving emergency commands from Earth at a rate of 7.8 bits per second.

Stellar navigation

Projecting from one side of the forward equipment module is the barrel of the star scanner. This optical navigation device will locate two stars that pass through its field of view at approximately 90° from each other and the spacecraft. These are compared to an on-board computer map of positions and luminances and adjust the gyroscopes to a triangulated position in space. The star scanner and attitude reference unit are mounted on a brazed beryllium optical bench inside the equipment module.

Attitude control—Magellan is a 3-axis stabilized craft required to perform almost continuous changing of its orientation in space as it circles Venus. This maneuvering is performed using gyros, thrusters and momentum reaction wheels controlled by a redundant pair of ATAC-16 computers in the spacecraft bus.

On each orbit of Venus, Magellan will rotate four times: away from the planet to aim its antenna Earthward, toward space to scan stars for calibrating exact position, again toward Earth to resume data transmissions, and back toward the surface of Venus for mapping. Throughout each mapping pass, the spacecraft continuously maneuvers in small increments to adjust the angle of the antenna to the changing curvature of the planet below.

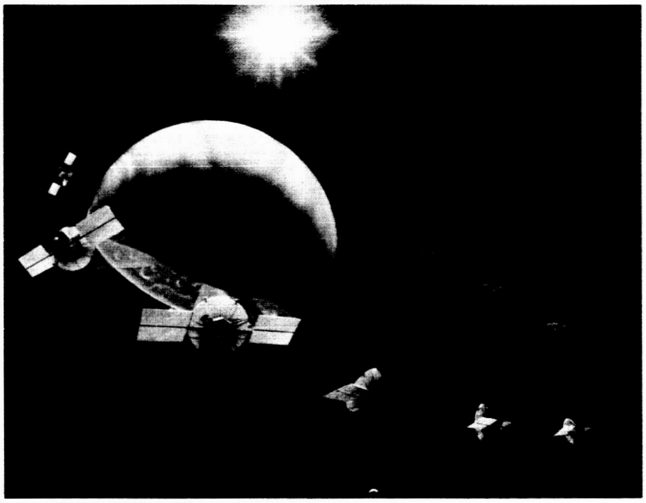

Figure 12 Magellan Orbital Maneuvers for Mapping and Transmission

In the primary mission, the 1852 orbits require 7408 major attitude changes in 243 days. If these attitude changes were done solely with thrusters, there would be more than 14,800 thruster burns for each of the spacecraft's three control axes (one to start a maneuver, another to stop it, and periodic burns to control the rate). Magellan would need immense fuel tanks, indeed!

However, Magellan is very miserly of the fuel in its single, small propellant tank. The repetitive attitude changes are accomplished with reaction wheels that use a principle called transfer of momentum. To illustrate, imagine rapidly stirring a glass of iced tea with a spoon. When released, the spoon will begin to spin around the glass with the water. The water was given momentum by the stirring spoon, then transferred some of that momentum back to the spoon.

On Magellan, small reaction wheels spinning very fast impart some of their rotational momentum to turn the spacecraft. The spacecraft is stopped or reversed in its rotation by transferring momentum back to the reaction wheels in the form of wheel speed. Three momentum wheels—one for each axis of rotation—are located in the forward equipment module.

In theory, this system could work on its own forever. But because of outside forces on Magellan, the stored momentum in the wheels will become inaccurate over time. Left uncorrected, the probe would err increasingly in the aim of its antenna. Therefore, thrusters are fired briefly once each orbit to restore the momentum wheels to their proper speed. Gyroscopes in the attitude reference units (ARUs) provide reference measurements for the amounts of rotation to be commanded, and tachometers on the reaction wheels determine the amount of thruster firing to "desaturate" the momentum buildup.

Electrical power—The probe operates on 28 volts DC fed through a power conditioning unit in the equipment module from either the solar arrays or a pair of nickel-cadmium batteries. Either battery could handle spacecraft power requirements alone should the other fail.

Solar panels—The two square solar panels, 8.2 feet on a side, can supply 1200 watts. With the arrays deployed, Magellan spans 30.6 feet from tip to tip of the panels. The light-colored lines visible on them are solar reflectors to keep the temperature of the arrays below 239°F even in full sun. Approximately 35% of the surface is reflective mirrors.

The panels are hinged for stowage in the shuttle and deployed while in Earth orbit. At Venus, they rotate to follow the Sun. Solar sensors on the panel tips and a control package in the multi-sided equipment bus maintain their sunward orientation. The honeycomb aluminum backing structure, arms and oversized joints enable the panels to withstand forces up to seven times Earth gravity that will be produced by the Venus orbit insertion burn.

BUS

Immediately below the large box of the forward equipment module is the 10-sided spacecraft bus built as a spare for the Voyager project. The bus is a bolted aluminum structure with aluminum cover plates. The bus is 16.7 inches high and approximately 6 feet across. Each of its ten compartments has enclosures for electronics 16.4 by 18.7 by 7 inches. The opening in the middle of the ring holds the hydrazine fuel tank for the liquid propulsion system.

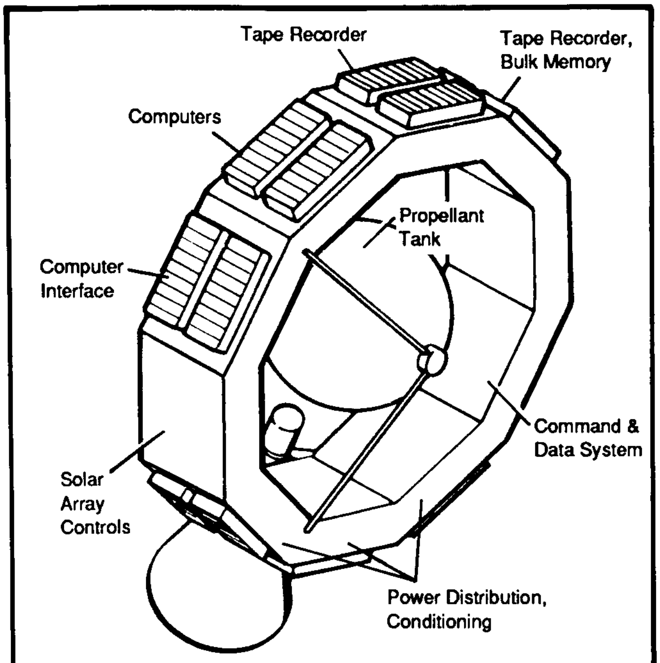

Figure 13 Spacecraft Bus

The bus compartments contain computers, the input/output interface between the computers and Magellan subsystems, tape recorders, solar array controls, bulk data storage, and solid motor separation controls.

One minute, nonfunctional but intensely meaningful element affixed to the bus exterior is a microdot about the size of a large postage stamp. On it are the signatures of some 10,000 people who have been involved with the Magellan program during its life.

Computers—Magellan's brains are ATAC-16 computers and the distributed command and data system. All computers are in redundant pairs as insurance against a breakdown; all are fully reprogrammable; and all are modified Galileo equipment.

The command and data system (CDS) decodes and distributes commands received from Earth stored in its bulk memory or tape recorders. It also prepares science data for transmission. Attitude and articulation commands received from Earth feed through the data bus to the ATAC-16 computers. These regulate the position of Magellan and its back-and-forth changes between data gathering and transmitting.

Data storage—Redundant tape recorders provide storage for 1.8 gigabits of radar data. In addition to tape storage, a bulk storage unit holds 5 kilobytes of engineering data in the event a real-time transmission of telemetry from Magellan is interrupted. All commands to the spacecraft are stored for execution at later, specified times. There are no real-time commands.

Pyrotechnical controls—Attached to the underside of one bus compartment is a box containing the control electronics that arm, disarm and fire various explosive bolts, pin-pullers and other mechanisms. These enable separation of the spent solid rocket motor and release of the solar panels from their stowed position.

PROPULSION

Propulsion equipment that is part of the Magellan spacecraft includes the solid-fuel Star 48B rocket and a 24-thruster liquid propellant system. The propulsion module structure provides precisely aligned attachment of the solid motor, as well as the liquid propellant thrusters and associated plumbing.

Solid motor—The Star 48B is the same motor that has been used to send commercial communications satellites into geosynchronous Earth orbit. The "B" denotes a motor using the newer, light-weight, graphite-composite thrust cone. The motor weighs 4721 pounds, of which 4430 pounds is propellant.

The solid rocket motor's 1.3 million pounds of thrust will deflect Magellan's trajectory into orbit around Venus. Prior to installation in the space shuttle, the motor is aligned with the spacecraft's center of gravity to within 0.1 inch for accurate direction control and to prevent the spacecraft from being tumbled.

Liquid propellant system—The 24 multipurpose liquid propellant thrusters provide guidance and attitude control. Positioned in the middle of the multifaceted spacecraft bus is the single tank containing 293 pounds of hydrazine monopropellant. A helium tank is attached to the struts of the propulsion module structure and will be used to offset a drop in the pressure of the hydrazine system that reduces thruster efficiency. The pressurant will be particularly important if Magellan's trajectory requires a major corrective firing of the thrusters that drops the system pressure.

At each of the four outboard tips of the propulsion structure are clusters of six thrusters: two 100-pound, one 5-pound, and three 0.2-pound thrust. The large motors, aimed aft,

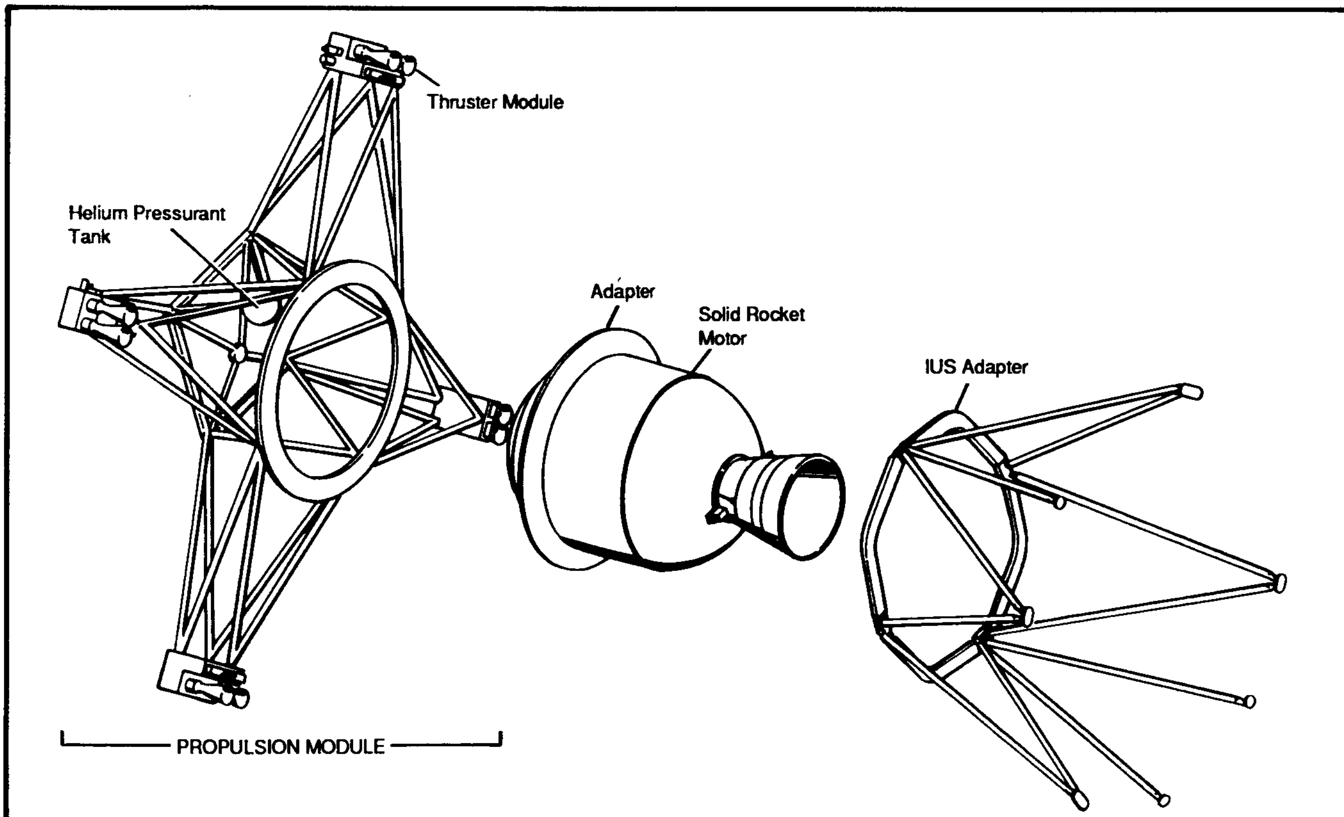

Figure 14 Propulsion Elements

are used for steering in the midflight course corrections and the Venus orbit insertion maneuver. The 5-pound motors, aimed sideways to Magellan's centerline, stabilize the spacecraft from rolling during the same maneuvers.

For the duration of the mapping mission, the tiny 0.2-pound motors provide thrusts to desaturate the momentum wheels and can be used for attitude control if required. Eight point aft and four are aimed for roll control.

The propulsion module also provides the attachment points for the IUS adapter structure. Both structures are made of graphite-epoxy trusses with sculptured titanium end fittings. Explosive bolts release the adapter after IUS burnout and the Star 48B motor when it is spent.

THERMAL CONTROL

Magellan will be subjected to sunlight 2.3 times that which reaches Earth, potentially for several years. Shaded exterior spacecraft temperatures can plunge to -400°F Throughout the mission, the constant maneuvering of the probe will result in every facet being subjected to the ranges of heat and cold. Special effort was required for thermal control that would keep electronics from frying and moving parts from freezing, while adding little weight or need for electrical power.

Electronics housings are wrapped in multi-layered thermal blankets that insulate and reflect light (see detail). The outer layer of the blankets is a material called astroquartz. It is similar to glass fiber cloth, but more durable to withstand intense solar radiation. In fact, chemical binders normally in astroquartz to control flaking had to be baked out when tests showed that the light intensity at Venus could discolor them and eventually cause a buildup of heat.

The high-gain antenna, low-gain antenna struts and propulsion module structure are painted with a special, inorganic water-based paint developed by NASA's Goddard Space Flight Center to withstand intense solar light without discoloring. Electronics compartments in the forward equipment module and equipment bus have louvers which can open or close to regulate the dissipation of heat from inside the spacecraft. Covering these openings and strips of the solar arrays are thin mirrors to reflect sunlight. The mirrors have been etched to diffuse reflections that could bake some other exterior part of the spacecraft.

The net effect of these materials is that the probe will tend toward cold temperatures rather than hot. To assure that some cold-sensitive components do not become too cold, electric heaters and flexible heater blankets have been installed inside housings or wrapped around fixtures, such as the solar panel articulation bearings.

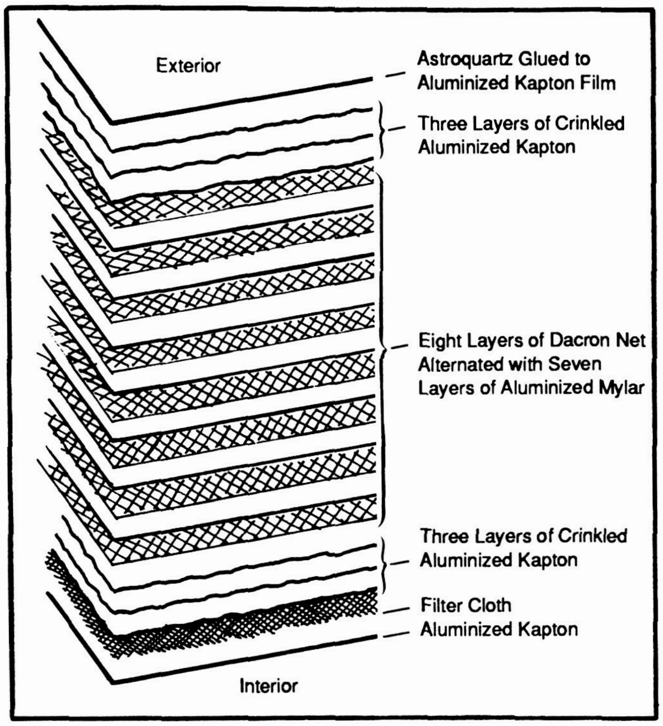

Figure 15 Thermal Blanket Construction

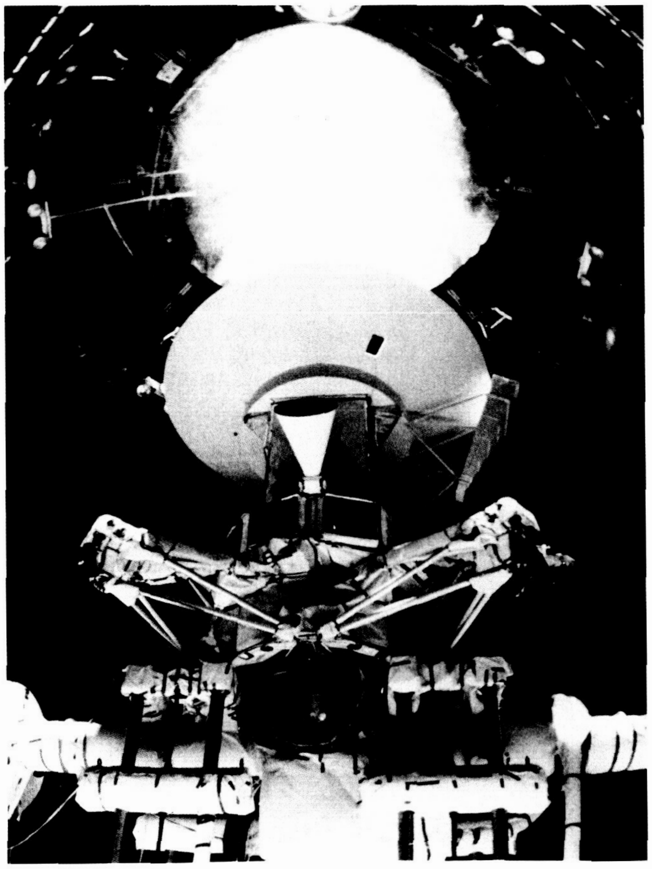

Figure 16 Thermal Testing of Spacecraft

SOFTWARE

Magellan is a spacecraft that can do a lot of its own thinking if problems arise. In the past, space missions often produced huddled conferences of experts on the ground to determine ways of working around a malfunction. Taking advantage of advances in fault detection software design, Magellan itself can analyze problems that occur and carry out a series of alternative remedies.

Minor or slowly developing problems revealed by telemetry will be managed by ground control. However, time-critical or mission-critical malfunctions will be detected, analyzed and dealt with by two on-board fault protection systems: one software system for attitude control and the other for the rest of the spacecraft.

Problems in the attitude control are treated "holistically" in a full-system health analysis to ascertain the integral cause and remedy. Other spacecraft malfunctions are managed on an individual basis by software in the command and data system. Only if all efforts fail will Magellan turn, aim its antenna Earthward and call for help.

Although some of the spacecraft control software was inherited from the Galileo Jupiter mission, most is new because of differences in the control system and mission. Ninety percent of the 6000 lines of attitude control software is new, including 2000 lines for fault protection. The 18,000 lines of code for the command and data system is 20% new and 35% is modified Galileo code. Its fault protection software totals 1500 lines.

Spacecraft operation is controlled for several days at a time by commands sent from Earth and stored for playback. This method requires very accurate navigational data that is updated frequently.

Control of the radar system is performed with Radar Mapping Sequencing Software (RMSS). This and attitude control commands are in a simplified form on mission control computers in Denver and at NASA's Jet Propulsion Laboratory. For most commands, engineers simply select from a list and add parameters. The ground computers convert this into the Magellan system codes for transmission.

During the interplanetary cruise, these commands will span up to eight days of activity. During mapping, four days of commands are sent and updated every three days. The extra day provides a safety buffer for a delay in communications.

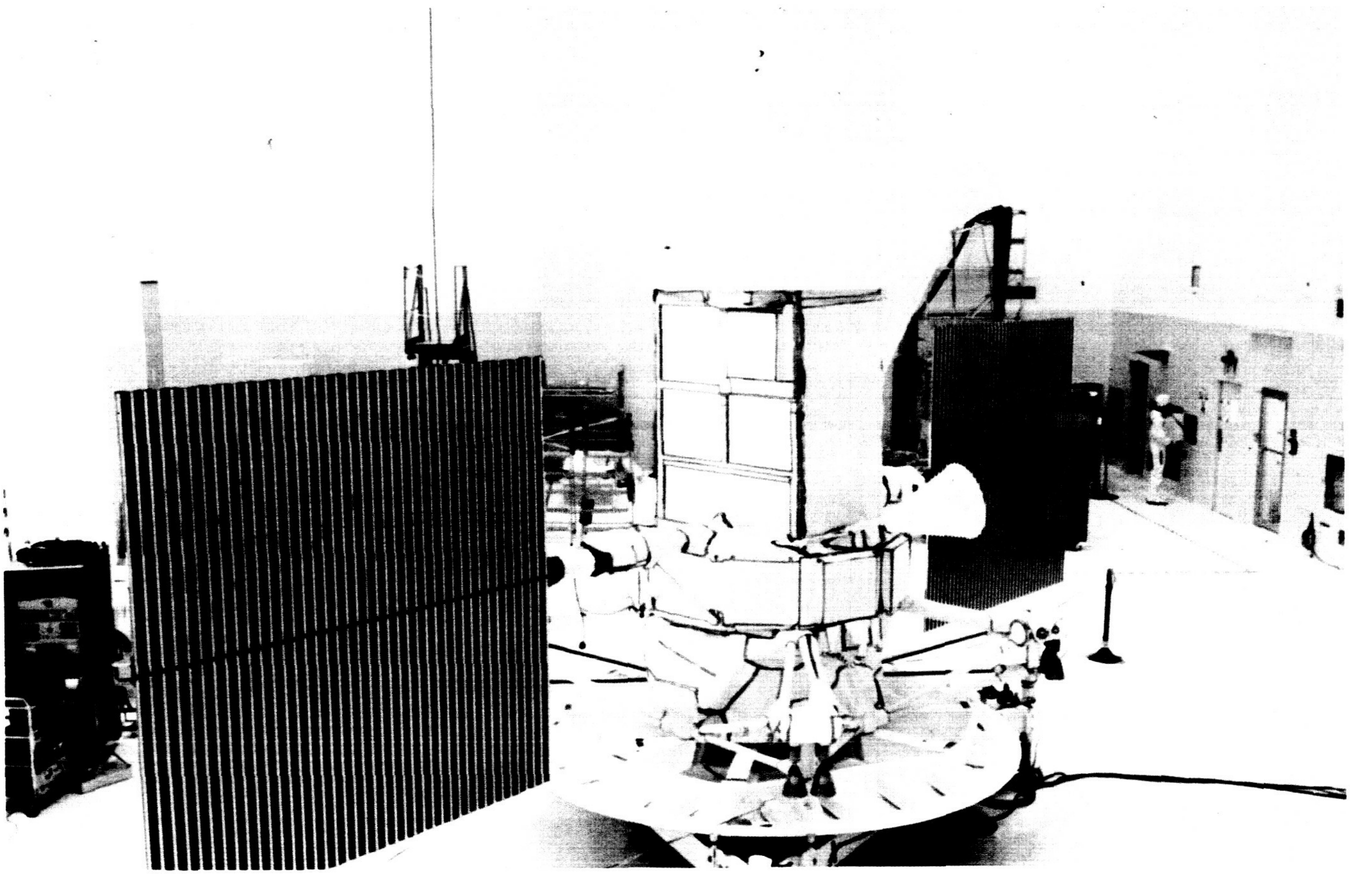

Figure 17 Magellan Spacecraft in Preflight Checkout at Kennedy Space Center

MISSION

The Magellan mission is the first of a spectacular series of events marking the return to deep space exploration by the United States. Following it are NASA launches of the Galileo Jupiter mission and the Hubble Space Telescope. In 1992, the Mars Observer spacecraft will be launched. The last deep space exploration mission was the launch of the Pioneer Venus probes in 1978.

Magellan was previously scheduled for launch in April of 1988, with arrival at Venus four months later. However, that date came into conflict with the rescheduling of the Galileo mission to Jupiter. Launching Magellan in April requires a longer flight to Venus but allows both missions to take advantage of optimal planetary positions that will not be repeated for two years.

Magellan now will use a more complex "Type 4" interplanetary trajectory in which the probe circles the Sun one and a half times in a 15-month game of catch-up with Venus. The longer route to Venus requires less thrust to depart Earth orbit and delivers Magellan to Venus at a lower and more manageable velocity.

LAUNCH

Magellan is scheduled for an April 28, 1989 liftoff. That date is the first of 29 consecutive days available for launch, determined by the relative positions of Earth, Venus and the moving spacecraft over 15 months. Each day has a brief launch window when Kennedy Space Center moves with the Earth's rotation into the position from which the shuttle can attain the orbit Magellan must use to reach Venus. This window grows from about 18 minutes to about 90 minutes and shrinks again over the 29 days.

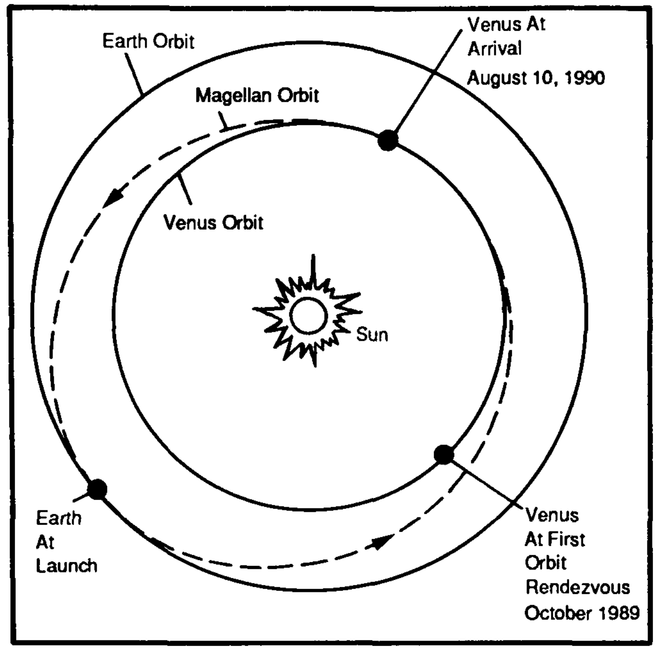

Figure 19 Heliocentric "Type 4" Trajectory

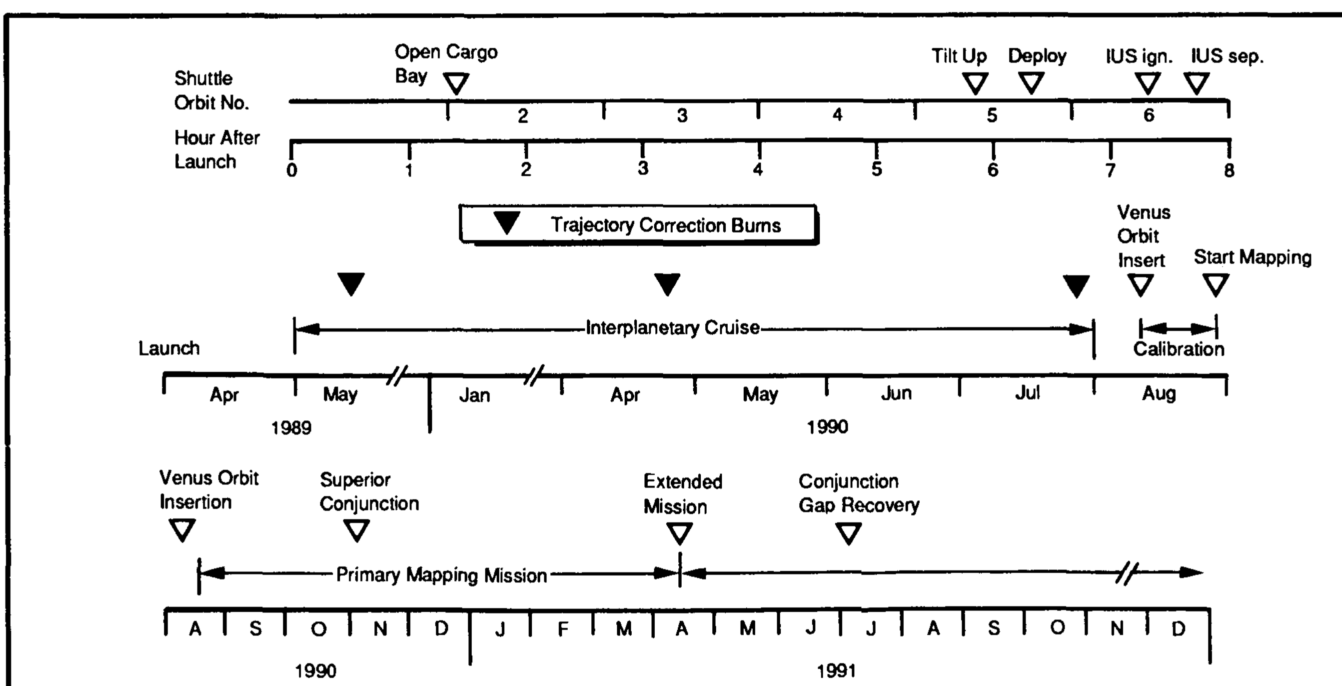

Figure 18 Mission Timelines

minutes later. The booster and Magellan then separate, coasting together for 8.75 minutes before guidance thrusters on the IUS fire to move it out of the Magellan orbit.

Figure 20 Deployment from Space Shuttle

Although Magellan could be launched any day of the four-week period, its arrival at Venus must fall within a 3-day rendezvous window in early August, 1990. Midflight changes of the spacecraft's trajectory will adjust for the actual launch date to time the rendezvous for August 10.

Magellan is carried in the cargo bay of the orbiter Atlantis attached to an Inertial Upper Stage (IUS) that provides the velocity necessary to escape Earth's gravity and reach Venus. At liftoff, the combined Magellan-IUS payload sits on a support cradle mounted to the walls at the aft end of the cargo bay. Umbilicals provide power and data links to the probe while it is aboard the orbiter.

Magellan's deployment begins six hours after liftoff when the shuttle orbiter is in the fifth revolution of a 160-nautical-mile orbit inclined 28.85° above the equator. The Magellan/IUS assembly is tilted on the cradle to a 58° angle. Ground and orbiter crews perform a final systems check, then springs on the cradle eject the craft. As Magellan and Atlantis move apart, the spacecraft's solar panels unfold.

About an hour later, when the orbiter has maneuvered a safe distance away, the two-stage IUS rocket is fired to begin the voyage. The IUS-powered acceleration is completed 6.7 minutes later.

CRUISE

During the interplanetary cruise, Magellan will become a man-made planet circling the Sun in an eccentric orbit transecting the orbit of Venus. The orbits first intersect four months after launch when Venus is elsewhere on its prescribed path. Eleven months later, when the orbits cross again, Venus will be at the rendezvous point.

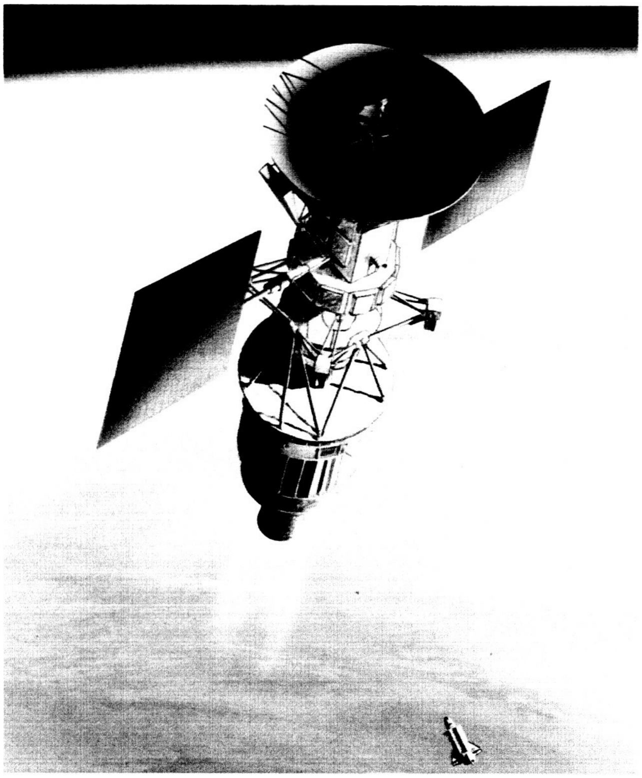

Figure 21 Magellan Cruise Configuration

Throughout this phase of the mission, monitoring of the spacecraft's condition and control of its systems will be performed at the Martin Marietta Astronautics facility in Denver. A mission control room there will be connected through the Jet Propulsion Laboratory to NASA's Deep Space Network (DSN) of radio communications dishes located in the Mojave Desert of California, at Canberra, Australia and at Madrid, Spain.

A Magellan spacecraft simulation lab, built at the Denver site during the two-year hiatus of shuttle flights, will enable the mission operations team to troubleshoot problems that might arise.

During the long voyage around the Sun, there are three critical burns of the probe's liquid-propellant guidance and attitude control thrusters. These correct the trajectory for the rendezvous with Venus. The burns are directed by the Denver mission control center using stellar navigation measurements made by the spacecraft, combined with signal Doppler shift and vector analysis performed on the ground. The first burn occurs within a few days of launch; the second a year later; and the third occurs ten days before the Venus rendezvous.

Four months after the Magellan launch, the Voyager 2 probe will shoot past Neptune, providing man's first close look at that planet and Voyager's last look at our solar system. Although the DSN will be handling signals from both missions, conflicts are unlikely because Magellan only requires an engineering data exchange every several days.

On arrival at Venus, August 10, 1990, the solid propellant rocket is fired to insert the spacecraft into its elliptical, polar mapping orbit and then is ejected. This critical event occurs when the spacecraft is on the side of Venus away from Earth and communications are blocked by Venus. Just before the communications blackout, the flight control team will transmit the commands for automated firing of the rocket. Even when the spacecraft is clear of Venus, the data confirming the success of the burn will take 20 minutes at the speed of light to reach Earth.

The final orbit comes to within 155 miles of Venus at its closest point (periapsis) 10° north of the equator, and is 4977 miles away at its most distant point (apoapsis). Magellan completes one orbit every 3.15 hours.

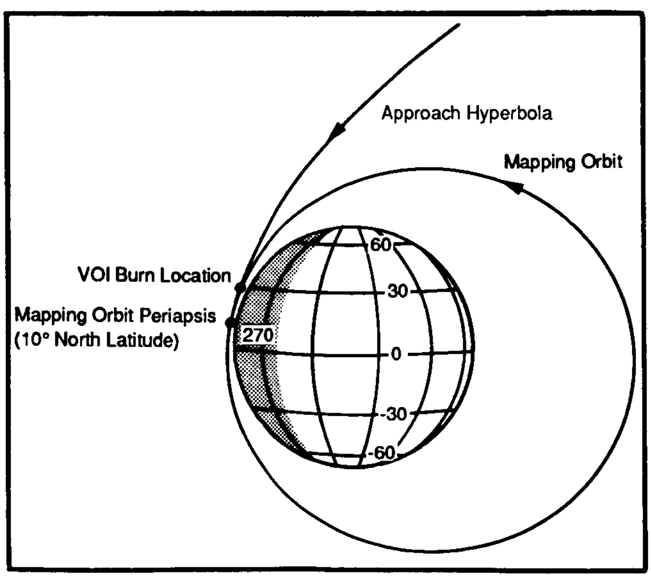

Figure 22 Mapping Orbit Insertion

For approximately 18 days, the spacecraft performs a series of position adjustments and instrument calibrations. This includes a test of the synthetic aperture radar that will provide the mission's first picture data of the Venusian surface, scheduled for transmission August 22, 1990. Mapping begins at the completion of this period.

MAPPING MISSION

Mapping for the initial mission lasts one Venusian day—243 Earth days. As Magellan flies in its north-to-south polar orbit, Venus rotates slowly underneath. Each of the 1852 passes of the spacecraft will allow the SAR to image a swath of landscape 10 to 17 miles wide and 10,000 miles long during a 37-minute mapping pass.

As the spacecraft passes over the south pole, it stops mapping and begins a maneuver to point its antenna at Earth. For about one hour, it transmits data back to the DSN antennas. A second maneuver at the orbit's apoapsis aims a star scanner to locate a pair of reference stars that are 90° to the probe. The locations are compared to a star map in Magellan's memory to verify its position in space.

After the star calibration, the spacecraft re-orients itself toward Earth and resumes data transmissions for another hour. As it passes the north pole of Venus, yet another maneuver places it in mapping position again.

Every three or four Earth days, the probe will receive updated instructions from mission control during the data

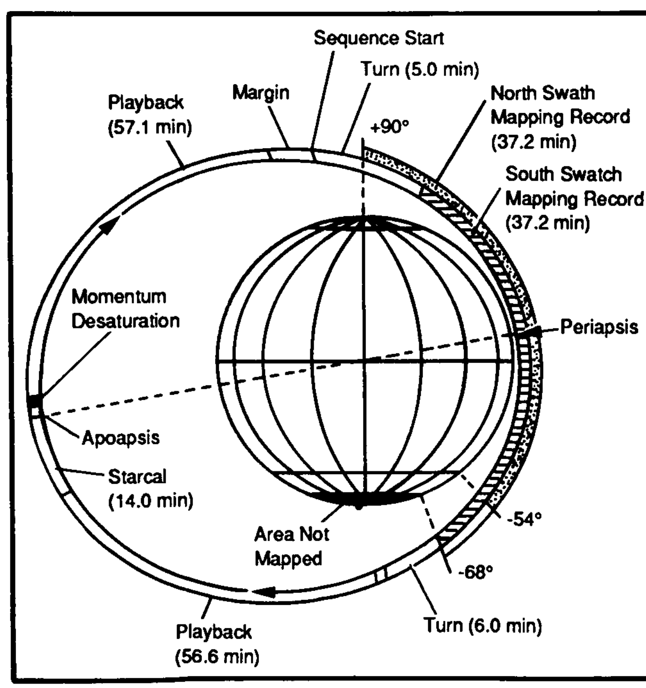

Figure 23 Mapping Orbit Operations

transmission periods. These instructions fine-tune mapping in the next four days based on what came before and what is known from existing Venus information. There are 950 commands in a typical upload of mapping instructions.

The surface swaths scanned by the SAR overlap, particularly at the north pole. Therefore, the swaths will be staggered with every other one beginning slightly below the north pole and extending closer to the south pole. This will reduce excessive overlap and provide some surface information from the southernmost parts of the globe.

When the radar system is in a passive state—not sending signals for SAR or altimetry—it can detect differences in the thermal microwave energy radiated naturally by Venus. During the primary mission, radiometry measurements will be taken after each SAR pulse to produce a global temperature map. Surface temperature variations provide valuable clues to the composition of materials and chemical processes.

The map of Venus produced by the 243-day primary mission will have unavoidable gaps amounting to approximately 10% of the planet's surface. There will be a small, circular void around the south pole of Venus because Magellan's orbit and the time requirements of alternating mapping and data transmission result in that area's exclusion.

A larger, pole-to-pole gap is caused by a superior conjunction three months into the mission when Venus and Earth are on directly opposite sides of the Sun. The Sun will completely block or seriously degrade communications to and from Magellan for several days. The length of interference will depend on solar flare activity. During the superior

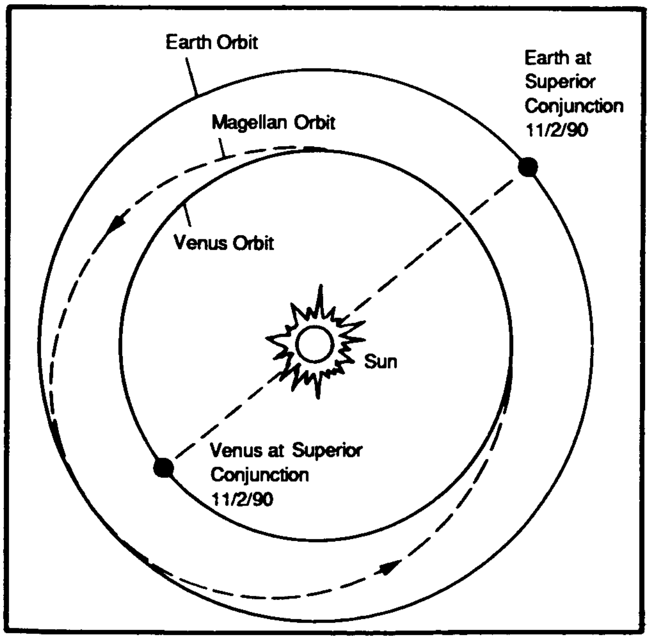

Figure 24 Superior Conjunction

conjunction, Magellan may be ordered to go into a safe position where the spacecraft ceases maneuvering to lock its solar arrays toward the Sun until it receives the command to resume mapping.

An irregular area in the southern hemisphere will also be left blank in the initial mission. This will be caused by the occultation (blockage) of the data transmission by Venus when it lies between Magellan and Earth for several minutes each orbit over a period of about a week.

In addition to these predictable gaps, scientists and mission planners recognize the possible loss of another 20% due to the unforeseen.

EXTENDED MISSION

Most of the missing 10-30% of the Venusian map is temporary because it may be filled on an extended mission. During subsequent 243-day cycles, the relative positions of the planets and the occultations will have changed sufficiently for Magellan to fill in the largest holes as it continues orbiting.

The extended mission will also permit stereoscopic imaging of areas that have drawn particular interest. The probe need only scan a previously mapped area from a slightly different angle or angles to produce 3-dimensional pictures.

Gravity measurements occur after the conclusion of mapping since they require Magellan to transmit radio signals to Earth while the spacecraft is close to the planet—just the opposite of the mapping mission. Through a technique known as radio interferometry, the signals received by the DSN are used to detect and map slight irregularities in the orbit caused by gravity variations. Large features with corresponding mass cause the spacecraft to accelerate and gain altitude. Surface depressions do the opposite.

An extended mission could last six to nine Venusian days (four to six Earth years) or more. The limited commodity controlling its duration is the propellant necessary for the attitude control thrusters to aim the spacecraft for mapping and data relay.

Magellan Mission Events Schedule

1989	April 28 May 13	Launch Course Correction
1990	April 23 August 1 August 10 August 10-28 August 28 November 2	Course Correction Course Correction Venus Orbit Insertion Instrument Calibration & Test Begin Mapping Superior Conjunction
1991	April 18 July 3	End of Nominal Mission Start Extended Mission Recover Superior Conjunction Gap

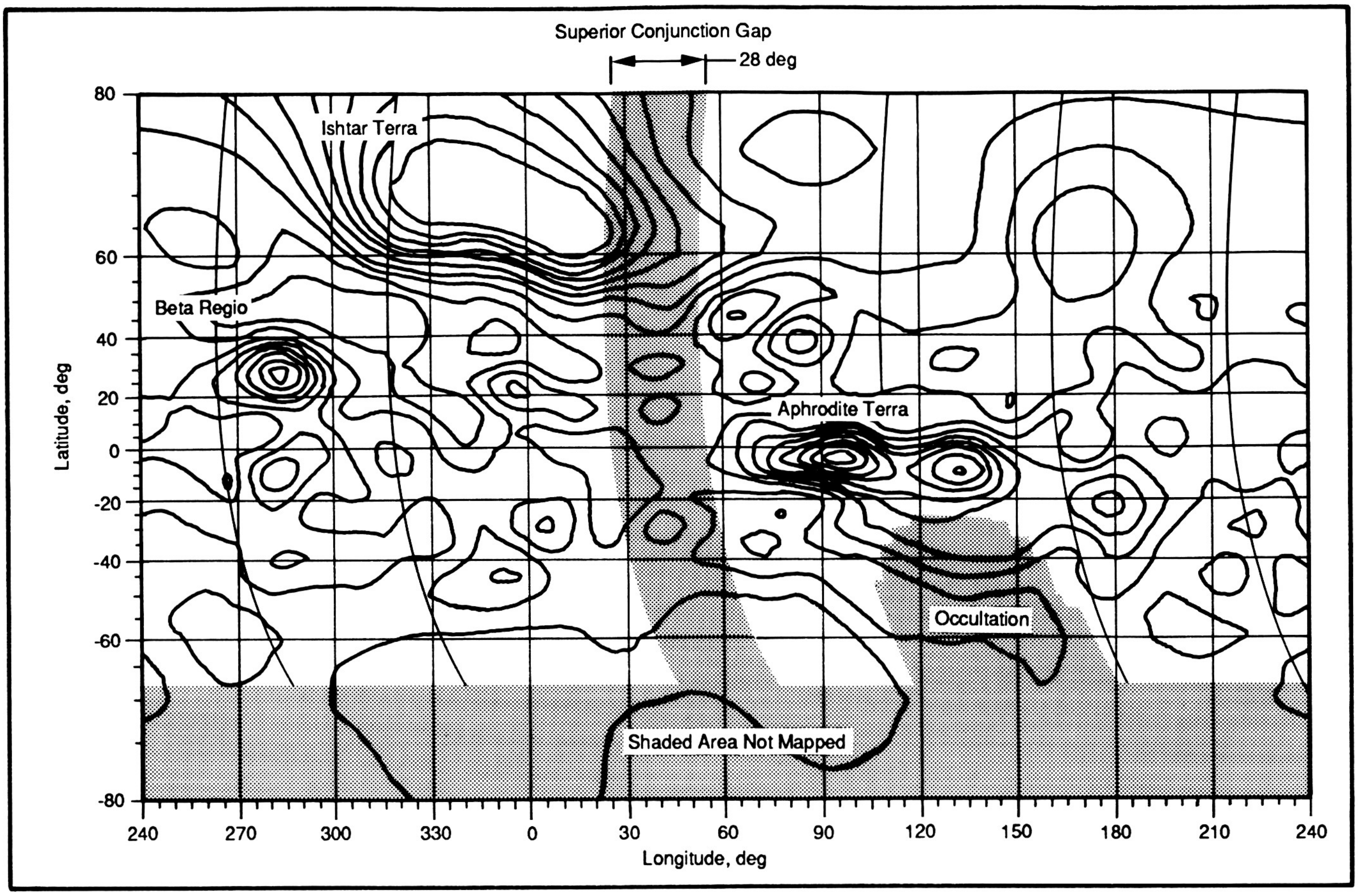

Figure 25 Gaps in Coverage of Venus

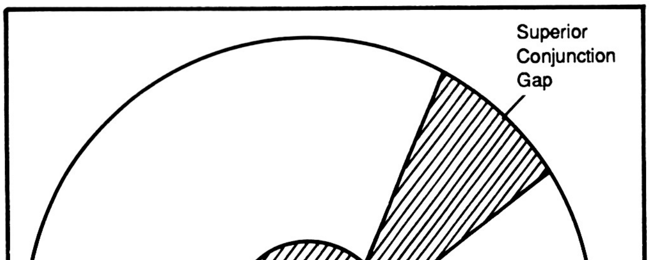

Figure 26 Planned Coverage of Venus (South Polar)

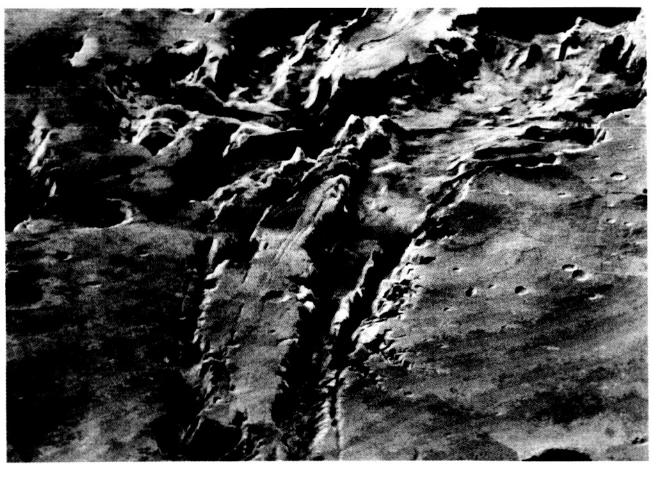

Figure 27 Valles Marineris on Mars in Computer-Simulated 3-D from Stereo Images

SCIENCE

Since Galileo's discovery of its clouds and umbral phases like those of Earth's moon, Venus has been very reluctant to give up her secrets. Earth-based observations revealed the rapid movement of the clouds and an upper atmospheric temperature of 125°F.

In recent years, a score of U.S. and Soviet space probes measured surface temperatures that would melt lead, sulfuric acid droplets at high altitudes and nearly pure carbon dioxide of intense pressure at low altitudes, and what appears to be lightning flashes possibly caused by volcanic activity.

Venus has been mapped by Pioneer 12 radar altimetry at 62 miles resolution. For example, a mountain range 1000 miles long and 100 miles across would be represented by 30 evenly-space altitude measurements. Nonetheless, Pioneer produced a map that revealed lowlands, highlands, and mountain ranges.

Since greatest variations in surface shapes appear in these highlands north of the equator, the periapsis of Magellan's orbit is north of the equator where it will provide its most detailed images.

In its primary mission alone, Magellan will collect more image data than all previous deep space missions combined. SAR images and altimetry will cover 70-90% of the surface, with a high probability of 90% coverage in an extended mission of mapping. The amount and resolution of the data will produce a more detailed global picture of Venus than exists for Earth, since much of Earth's geologic surface features are hidden or obscured by oceans.

Magellan will collect four kinds of planet-wide data:

1) Photograph-quality surface images revealing features as small as 300 feet across,

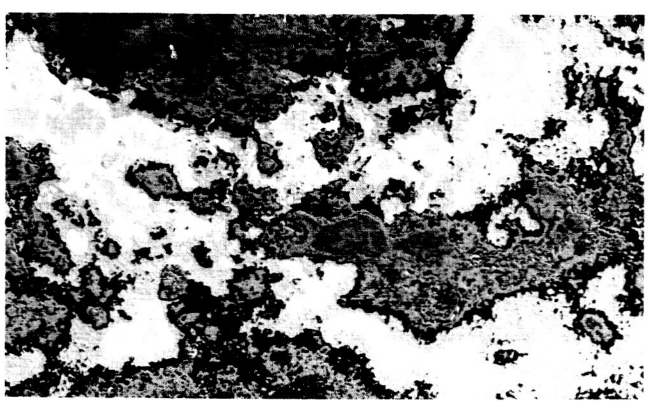

Figure 28 Pioneer Altimetry Map of Venus

2) Altitude topography accurate to 100 feet,
3) Gravity variations,
4) Radiometry of surface temperatures.

The completed Magellan spacecraft's capabilities exceed the science requirements established at the start of the program that specified 70% coverage at image resolution of 1640 feet and altimetry resolution to 164 feet.

By itself, detailed, global imagery of Venus will tell volumes about the planet's geology, environment, and evolution. In general, radar images will show smooth surfaces as very dark, while surfaces of rough, fragmented rock will be bright.

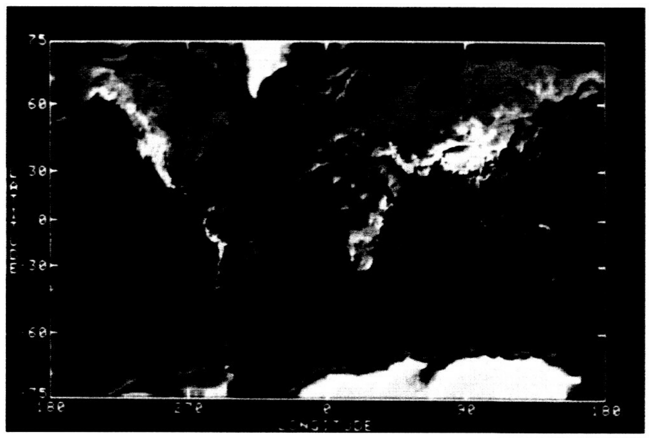

Figure 29 Earth As Seen at Pioneer Resolution

Pictures may indicate, as they have on Mars, whether water once existed on the surface. By counting meteor impact craters, scientists can determine the surface age, the activity of any volcanic features and the history and character of erosion. The images should reveal what global forces, such as plate tectonics or volcanism, prevailed in forming the planet.

By combining the various data, even more knowledge can be acquired from the Magellan mission.

SAR image data and the altimetry will be combined in large mosaics used to produce detailed topographic maps of the planet. Initially, the entire planet will be charted on 20 maps of low resolution. Areas of special interest will be selected for 220 high-resolution mosaics covering 15% of the Venusian surface. These maps will reveal surface features of selected areas to the finest detail Magellan can provide.

The altimetry data will be matched to a refined gravity map of the planet, enabling scientists to equate surface features

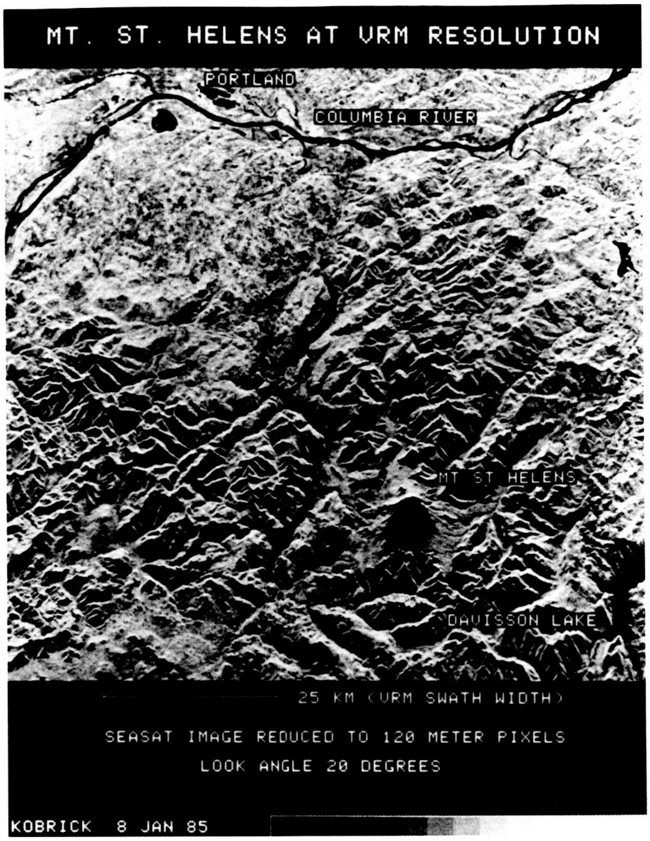

Figure 30 Oregon and Washington Area As Seen at Magellan Radar Resolution

to variations in planet density that slightly affect its gravitational pull. From this, interior geological forces can be interpreted.

Combining radiometry data with surface imagery will provide clues to the chemical composition of the surface and chemical processes occurring on and above the surface. Scattering of the radar signals by the surface will further indicate composition.

This knowledge will fill a gap in the broader understanding of the inner solar system, including Earth. It will give us a vastly clearer view of how and why planets are different, the mechanisms that render worlds inhospitable, and the limited conditions under which life has survived and evolved on Earth.

KEY PERSONNEL:

Dr. Lennard Fisk—NASA Associate Administrator for Space Science and Applications

Dr. William Piotrowski—NASA Manager, Magellan Program

John Gerpheide—Jet Propulsion Laboratory, Magellan Project Manager

Charles Brown—Martin Marietta Space Systems, Magellan Project Director

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National Aeronautics and Space Administration
Jet Propulsion Laboratory
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CONTRACTORS—Major Elements:

Ball Aerospace	Star Scanner
Boeing Aerospace	Inertial Upper Stage
LEOS	Electric Power Subsystem
Morton Thiokol	Star 48B Solid Rocket Motor
Motorola	Base Band Data Processing
Odetics	Tape Recorders
Ralph M. Parsons Co.	Solid Rocket Motor Adapter, Thruster Mounts, Solar Panel Supports
Rocket Research Corp.	Rocket Engine Modules
Singer	Attitude Reference Units
Spectrolab	Solar Arrays
Sperry	Reaction Wheels
TRW-PSI	Propellant Tank, Pressurant Tank

CONTRACTORS—Prime:

Martin Marietta Astronautics Group
P.O. Box 179
Denver, CO 80201
(303) 977-5364

Responsibility:
Overall spacecraft design, development, assembly and testing; also launch operations and mission operations support at control centers in company's Denver facility and the JPL control center in California. Contract value to date: $216 million.

Hughes Aircraft Company
Space and Communications Group
Group Communications
P.O. Box 92919
Los Angeles, CA
(213) 648-0884

Responsibility:
Design, development assembly and testing of synthetic aperture radar electronics and altimeter antenna. Contract value to date: $99.7 million.